AFIT's Systems Engineering Case Studies

An Assessment of the Continuum of the Systems Engineering Process

U.S. AIR FORCE

Presented to the Systems Engineering Committee of the National Academy of Science

March 2007

John Griffin

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Outline

- The Generic SE Process – Concept to Initial Operational Capability (IOC)
- What we have now
  - Joint Capability Integration and Development System (JCIDS)
  - DoDD5000 / National Security Space Policy 03-01
- What AFIT teaches
- What lessons do the case studies contain
- Observations

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Concepts to IOC

- **Need to "Pull the thread" from Strategy to Concept to IOC**

Defense Strategy

Joint Warfighting

Capabilities-> Attributes
Measures of Effectiveness

Gaps

Conceptual Solutions

Concept/ Systems

System Requirements

System Design

Build

Integrate

Test / Verify/ Validate

Production

Operation

Disposal

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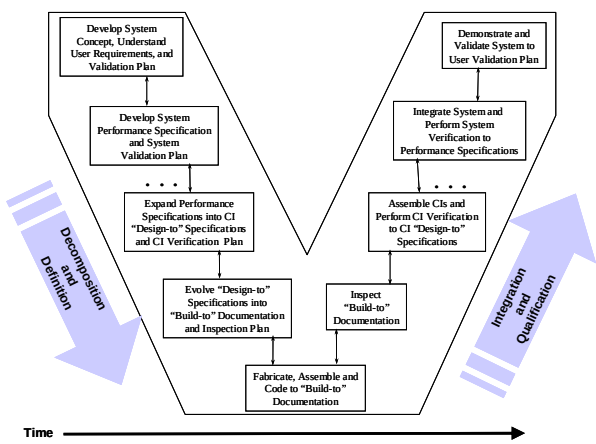
Visual Model

- **Systems Engineers often visual the activities and task to "pull this thread" in a V-model.**



from: Forsberg, Mooz, Cotterman; "Visualizing Project Management"

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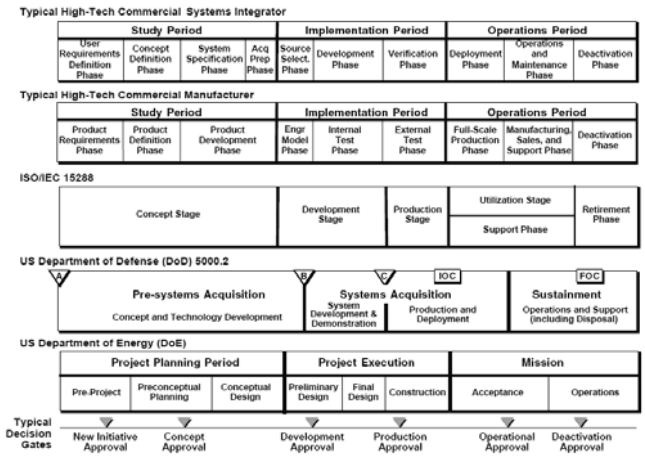
Multiple SE Processes?



Regardless of DoD Policy, Instruction or Guide, these still must be done

from: DAU Acquisition Guidebook, 2006

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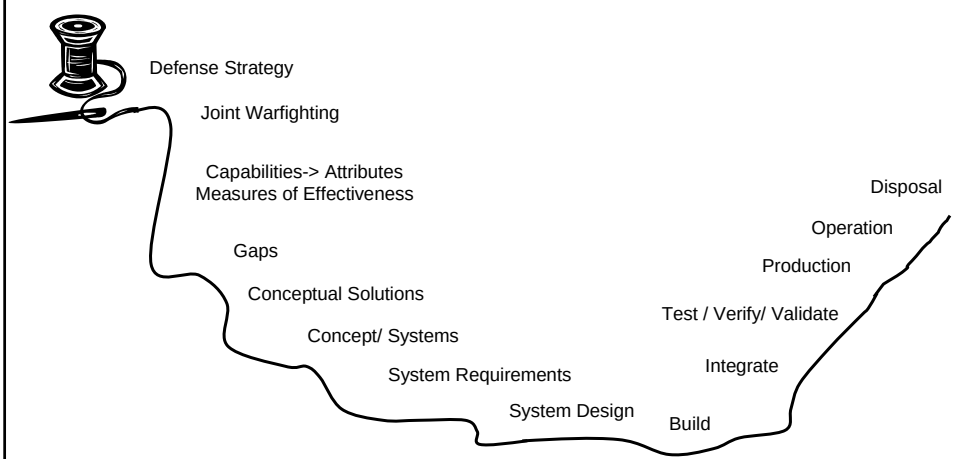
Concepts to IOC



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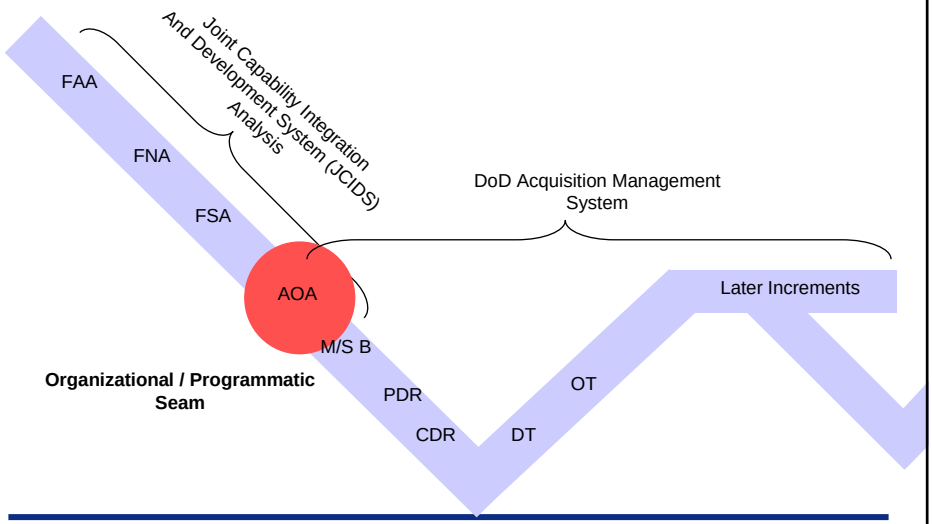
Concepts to IOC



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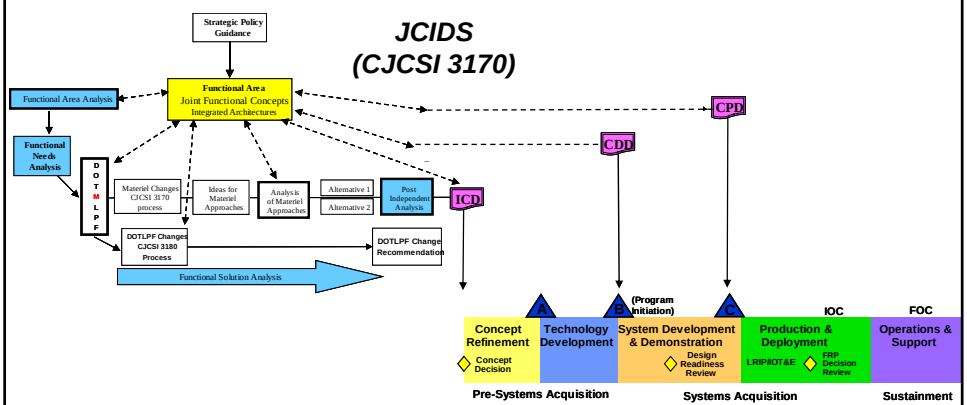
Concepts to IOC



JCIDS
(CJCSI 3170)

Acquisition
(DOD 5000/NSS 03-01)

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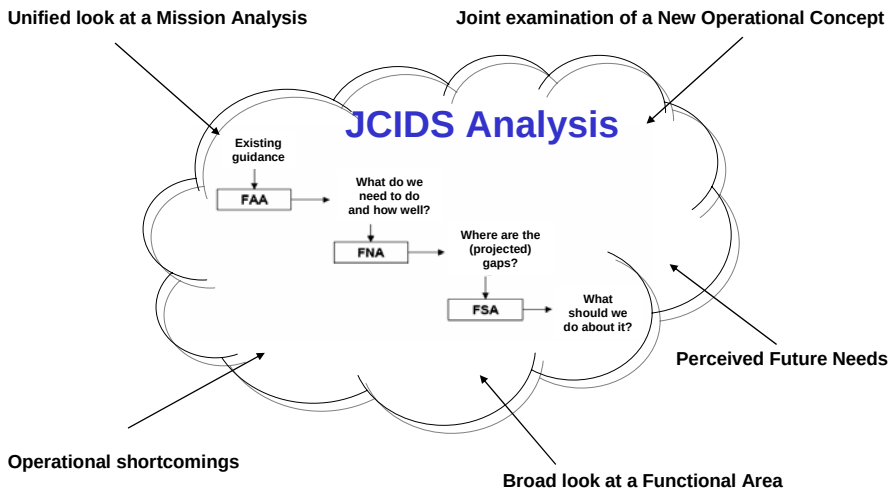
JCIDS Triggers



White Paper on Conducting a Capabilities-Based Assessment (CBA) Under (JCIDS) JCS J-8, January 2006

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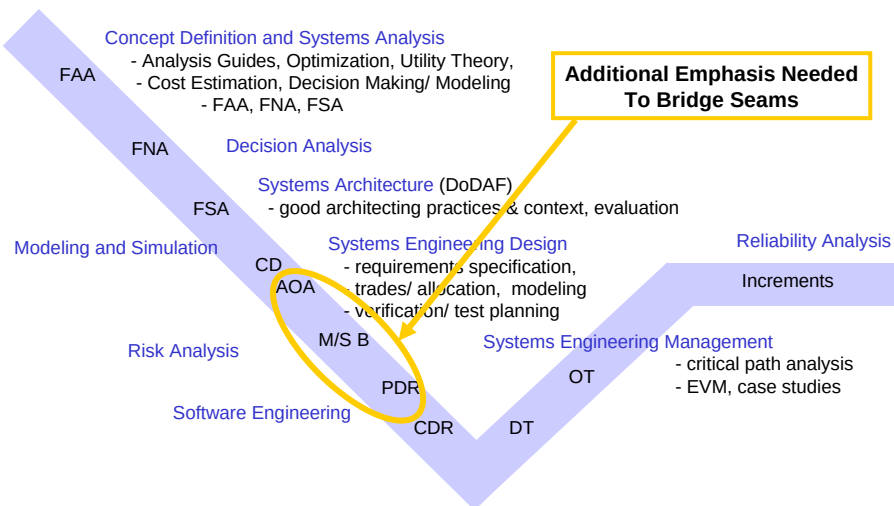
What AFIT teaches in Systems Engineering



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Systems Engineering Case Studies*

C-5 Galaxy

B-2 Spirit

F-111

Currently available case studies provide good and bad examples of pre-acquisition activity

- New cases underway

Hubble Space Telescope

TBMCS (Theater Battle Management Core Systems)

JASSM (FOUO)

* Available at: www.afit.edu/cse/

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Case Study Process

- Highly Disciplined
  - Depth of Study
  - Number of Interviews
  - Amount of Data sources and access
  - First and second reviews of draft case
- Objectivity of authors and editors
  - Wide review
- Scope
  - Concentration
- Effort
  - 1-2MY/ 12-18 month

This is Hard!

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C-5 Galaxy

- Over 34 years of successful operational performance in support of the Nation's cargo/transport needs
  - USAF inventory of 126 C-5 aircraft :74 C-5A, 50 C-5B, 2 C-5C
- During Operation Desert Storm, C-5 fleet carried 46% of the total inter-theater cargo, flying only 29% of the cargo missions
- In Operation Iraqi Freedom,

the C-5 fleet carried 48% of total cargo flying only 23% of the cargo missions

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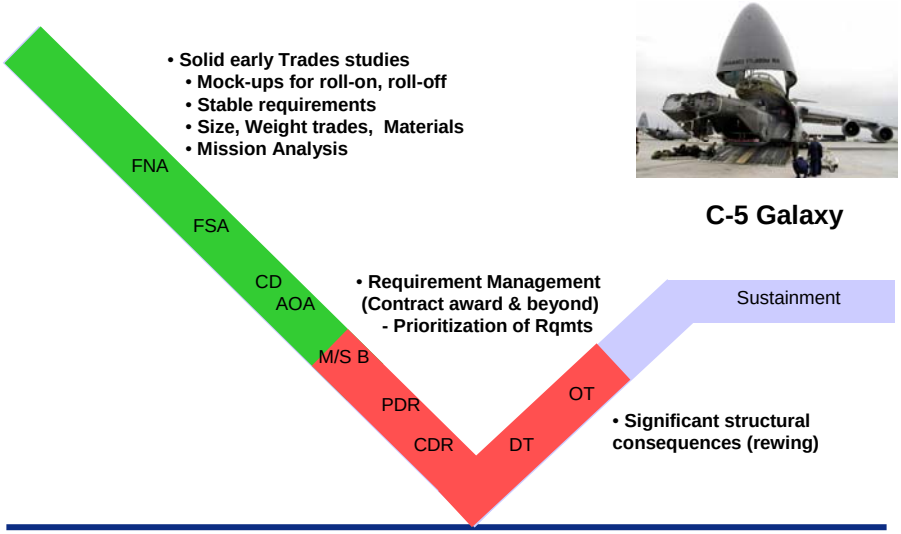
Mapping the C-5 to Today's Process



C-5 Galaxy

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C-5 Learning Principles

- **LP #1. Systems requirements need to integrate the User (warfighter), planners, developers, and technologists into a well-balanced, well-understood set of requirements**
- **LP #2. Total Package Procurement Concept (TPPC) was a fixed-price, incentive fee contract strategy for the design, development, and production of 58 aircraft. Invented to control cost growth, it was the underlying cause for the overrun**
- **LP #3. A Weight Empty Guarantee was included in the specification and in the contract as a cost penalty for each delivered overweight aircraft. This measure dominated the traditionally balanced requirements resulting in a major shortfalls in wing and pylon fatigue life**
- **LP #4, Independent Review Teams (IRTs) were to assemble national experts to examine the program and provide the best advice and recommendations to the government in structures design, technology and service life**

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F-111 System Description

- In 1950s, USAF needed a replacement for F-100, F-101, and F-105 fighter-bombers
  - Mach 2+, 60,000 foot altitude
  - All-weather fighter, originally specified as capable of vertical and short takeoff and landing (V/STOL)
- Many firsts
  - 1st terrain-following radar, allowing it to fly at high speeds and low altitudes
  - 1st production aircraft with variable swing wings
  - 1st crew escape module

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Mapping the F-111 to Today's Process

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F-111

F-111 Synopsis

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- **LP #1: Ill-conceived, difficult-to-achieve joint requirements and attendant specifications made the F-111 system development extremely costly, risky and difficult to manage.**
- **LP #2: Systems Engineering managers (both Gov't and contractor) were not allowed to make the important tradeoffs that needed to be made in order to achieve an F-111 design that was balanced for performance, cost and mission effectiveness (including survivability) and the attendant risk and schedule impacts.**
- **LP #3: The F-111 suffered from poor communications between the Service technical staffs, and from over-management by the Secretary of Defense and his staff, which restricted the System Program Office (SPO) Director from applying sound systems engineering principles.**
- **LP #4: The F-111, like any complex weapon system development program which provides new war-fighting capability, had areas of risk that came to light during RDT&E even though there was perceived low risk in the design.**
- **LP #5: Cancellation of the Navy F-111B in 1968, after the bi-service design was frozen, and production of the Air Force F-111A was well underway, had a lasting impact on the United States Air Force F-111 performance and cost.**

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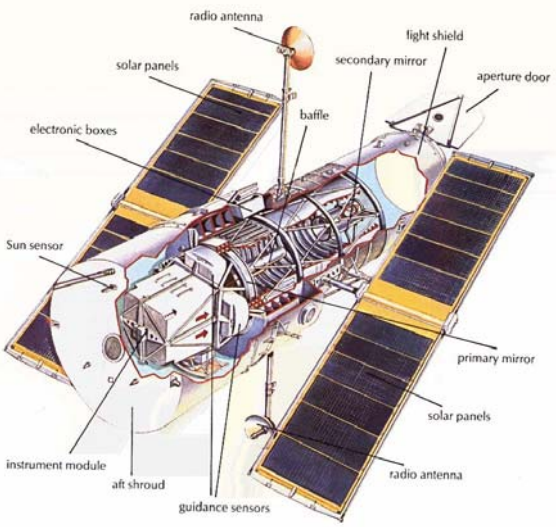
Hubble System Description



- Launched in 1990, scheduled operation through 2010
- Permanent space-based observatory - planned regular servicing missions
- 2.4-meter reflecting telescope deployed in low-Earth orbit (600 kilometers) by the Space Shuttle Discovery
- Complement of science instruments, spectrographs cameras and fine guidance sensors operating near-infrared into ultraviolet spectrums providing resolution of 0.1 arc-seconds

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HST Successful System

- **Over 100,000 observations of more than 20,000 targets have been captured for retrieval**

Tadpole Galaxy

Mapping Hubble to Today's Process

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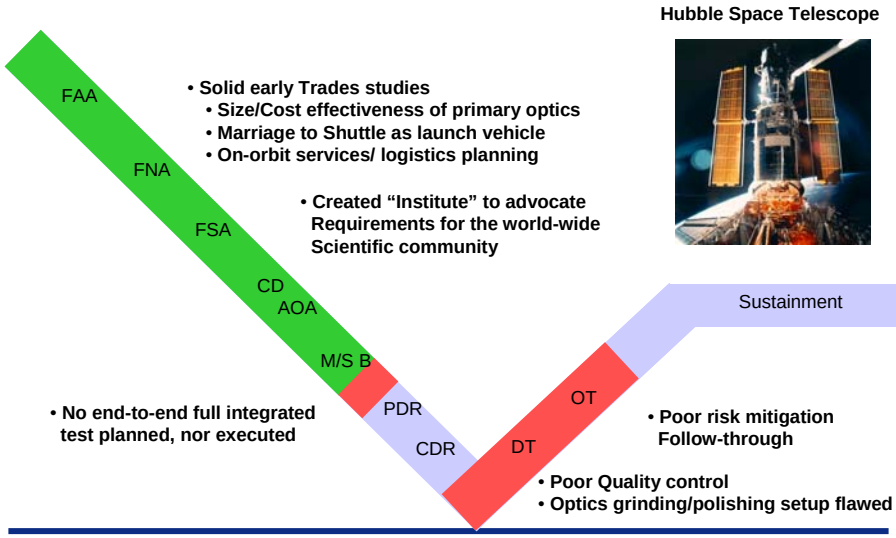

Hubble Learning Principles

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- **LP #1. Early and full participation by the customer/user throughout the program is essential to program success.**
- **LP #2. The use of pre-program "Phased Studies" to broadly explore technical concepts and alternatives is essential and provides for a healthy variety of inputs from a variety of contractors and government (NASA) centers.**
- **LP #3. Provision for a high degree of systems integration to assemble, test, deploy and operate the system is essential to success and must be identified as a fundamental program resource**
- **LP #4. Life Cycle Support Planning and Execution must be integral to design. Programs structured with real life cycle performance as a design driver will be capable performing in-service better, and will be capable of dealing with unplanned, unforeseen events (even usage in unanticipated missions).**
- **LP #5. For complex programs, the number of players (government and contractor) demands that the program be structured to cope with high risk factors in many management and technical areas simultaneously.**

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B-2 Spirit

- Multi-role bomber combining survivability with ability to deliver massive firepower
  - Second generation stealth technology
  - Unique aerodynamic control scheme
  - High altitude delivery of precision guided munitions
- Combat proven
  - 33% of Serbian targets in opening weeks while operating from CONUS base
  - Wide variety of strike missions in Afghanistan, Iraq

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Mapping the B-2 to Today's Process

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B-2 Learning Principles

- **LP 1, Integration of the Requirements and Design Processes: Integration of the SPO requirement's team with the contractors' design, manufacturing and logistics Work Breakdown Structure (WBS) Task teams facilitated continual trade studies to assess the performance trade-offs against schedule, cost, and risk.**
- **LP 2, WBS Task Teams and Functional Hierarchy: The contract Work Breakdown Structure (WBS) stipulated the entire program content and tasking and the company organized the design/development effort into multiple teams according to the WBS. A vital distinction from many of today's IPTs was retaining the WBS Task Team membership throughout the functional organizations' various management levels.**
- **LP 3, Air Vehicle Reconfiguration: The identification of a major aeronautical control inadequacy just four months prior to the formal Configuration Freeze milestone necessitated a substantially revised design. While the program response to the crisis was rapid and effective, the magnitude of the impact on the downstream cost and schedule was not anticipated by the management team nor predicted by the systems engineering process.**
- **LP 4, Subsystem Maturity: The effect of the reconfiguration on the maturity of all the air vehicle subsystems was far greater than projected. It took longer than anticipated by the systems engineering process to recognize the growing problem of getting all the specifications updated. These iterations after PDR-2 resulted in the Vehicle Subsystems not achieving the Critical Design Review (CDR) milestone concurrently with the Structure, but rather five months later.**
- **LP 5, Risk Planning and Management: The program was structured so that all risks affecting the viability of the weapons system concept were identified at contract award and were structured as part of the program WBS work plans. Those initial risks were closed prior to PDR 2. The risk closure process continued throughout development and identified new risks and continuously identified new risk closure plans.**

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TBMCS System Description

- Theater Battle Management Core System (TBMCS) is an integrated air command and control (C2) system
- Performs secure, automated air battle planning and execution management for Air Force, multi-service, and allied commanders
- Provides the means to plan, direct, and control all theater air ops and to coordinate with land, maritime, and special ops elements
- Modular and scalable for air, land, or sea transport and the deployed configurations can be tailored to meet a particular contingency

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TBMCS Successful System

- Deployed worldwide as the mandated joint system that the JFACC uses to plan, manage, and execute the air battle
- Demonstrated very rich functionality: it can produce a very complicated integrated air battle plan
- During Operation Iraqi Freedom (OIF), the size of the Air Tasking Orders, which planned all sorties, well exceeded system performance parameters

Total Sorties Flown	41,404
USAF	24,196
USMC	4,948
USN	8,945
USA	269
United Kingdom	2,481
Australian	565

TBMCS in the Air Operations Center, Al-Udeid, Qatar

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Mapping TBMCS to Today's Process

TBMCS

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TBMCS Synopsis

- **LP #1: The government did not produce a Concept of Operations, key operational performance parameters, or a system specification for the contractor**
- **LP #2: The high-level system architecture and the government's mandates for software reuse and use of commercial software (COTS) products were contradictory and problematic for the system development**
- **LP #3: The system and subsystem design was severely hampered by the complexity of legacy applications and misunderstanding of the maturity and complexity of commercial and third party software**
- **LP #4: Systems and interface integration was highly complex - integrating third party software was an arduous process and required extensive oversight.**
- **LP #5: The lack of a firm requirements baseline made validation and verification very difficult. The scheduled-driven program often ran parallel tests without clear measures of success. Not being able to replicate the operational environment prior to acceptance test created severe problems.**

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JASSM System Description

- Joint Air-to- Surface Standoff Missile (JASSM) is an autonomous, stealthy, long range conventional, air-to-ground, precision standoff missile used by the US Air Force and US Navy
- Destroys high value, well defended fixed or relocateable targets, from ranges of over 200 nm
- Employed as a fully autonomous "Fire and Forget" Weapon
- IOC in 2003

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Mapping JASSM to Today's Process

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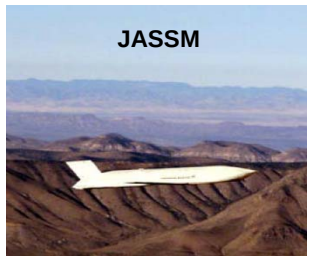

Emerged from ashes of TSSAM
- Requirements overload
- TSSAM Cost tripled

CD
AOA
M/S B
PDR
CDR
DT
OT

Reluctant Navy participation due to SLAM-ER
- Navy eventually bows out

Some stakeholders unhappy with resulting system trades
-System Reliability
-Un-implemented data link on base JASSM
-JASSM production, JASSM-ER program on hold

Acq Reform Pilot
-Only 2 performance req'ts with 1 at MOE level
-Contractor responsible for system trades

Minimal DT program
- M&S replaced robust flight test program
- Insufficient data to address reliability concerns

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JASSM Synopsis

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- **LP #1: JASSM implemented many OSD and SAF/AQ acquisition reform initiatives with mixed results**
  - **Increased Value on Past Performance, Mandated No-Mil Specs/Standards**
  - **Implemented Requirements Control Working Group**
  - **Applied Performance Based Specification, Configuration Control to Contractor**
  - **Used Contractor-centric Test and Evaluation (T&E) Plan**
  - **Elevated Importance of System Affordability, Rolling Down-Select**
- **LP #2: APPLICATION OF CAIV – Use of many COTS/NDI components and employment of non-traditional processes and suppliers. Objective req'ts traded off for lower cost.**
- **LP #3: GOVERNMENT TECHNICAL OVERSIGHT – Less than directed for traditional MDAP ACAT 1 programs, especially during transition to production and deployment phases**
- **LP #4: INTERPRETATION OF TRADE SPACE - Contractor given responsibility for all system performance below range and Missile Mission Effectiveness (MME), an MOE level capability (55 missiles to destroy a 17 target set). The contractor chose to design JASSM with high values for major elements of MME, which allowed a design that had lower free flight reliability.**
- **LP #5: USE OF MODELING & SIMULATION – Resulted in a small developmental flight test effort. Insufficient flight tests were scheduled to adequately address emerging concerns with respect to missile reliability.**

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Conclusions from Case Study Assessment

- Systems Engineering exists as a Continuum
  - From the beginning of the idea …
  - … to the disposal of the equipment.
  - There are no shortcuts
- Different tools, people, skills are necessary throughout the modified "V"
  - Teach the skills
  - Train and retain the people (ALL associated with implementing the SE process)

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Our Management Structure

- Development Planning (Capability Planning)
  - Existed in the past
    - Reported to Product Center commanders
    - Funded by PE 65808
    - Mission focused
      - Mission narrowly defined in today's view
      - Not adequate for Systems of Systems

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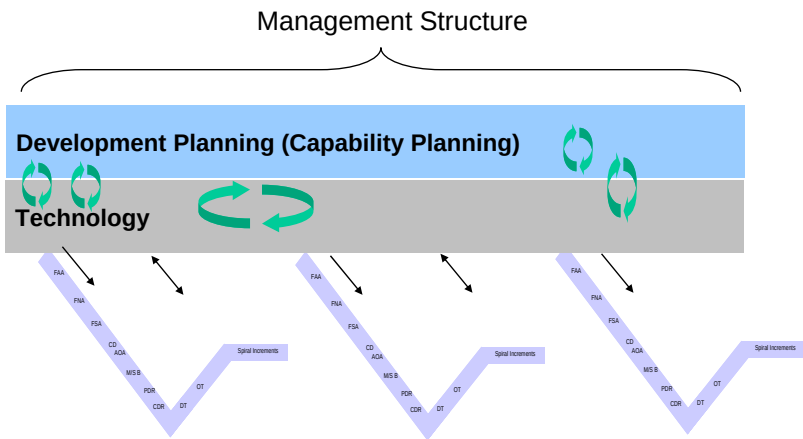
Capability Planning



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Observations

- We need the SE process to function end-to-end
  - Transition points are highest risk for failure - “SE escapes”
    - Concept Decision – AoA
    - CDD – M/S B
- Development Planning (Capability Planning) function is vital
  - Must be capability driven – analysis must span multiple domains
  - Users have the responsibilities, but neither the time nor the skills
  - Reconstituted product center XR shops
    - Skills not yet fully developed
    - Still excessively domain specific
    - Inconsistently funded
    - No clear role
- Technology is short-term focused

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BACKUP

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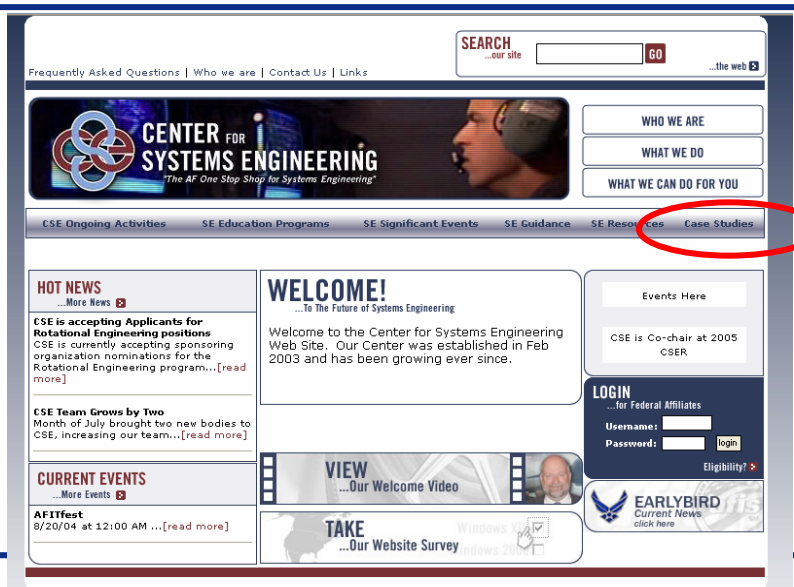
Case Studies
http://www.afit.edu/cse



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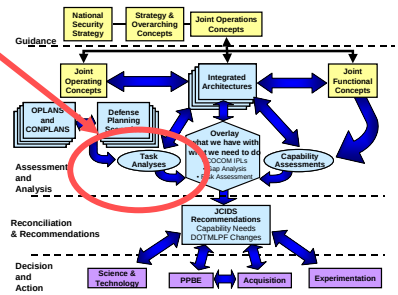
What we have now - Assessment

- **Usually good job of relating JCIDS effort to National Strategies, QDR, Joint Concepts, UJTL, Air Force Capabilities**
- **But, Task Analysis, per JCIDS and good Systems Engineering practice, should define the standard to achieve**
- **Measures of Effectiveness (MOE) by which to compare different solutions**

Our experience supporting AoAs has taught us that developing a good set of MOEs is usually a harrowing business.

-- Air Force Analyst's Handbook



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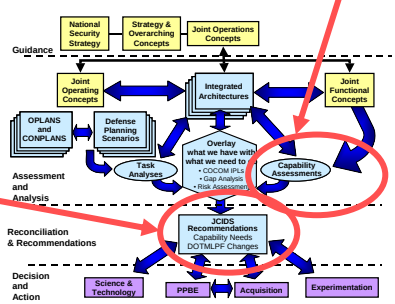
What we have now - Assessment

- **Without good Measures of Effectiveness, any Gaps in the Capability Assessment (Functional Needs Analysis) would be "hand waiving"**
- **Results in not giving a sound and full understanding of gaps/ root causes**
- **Solutions Analysis should give fair assessment to entire DOTMLPF* solution space**

* Doctrine, Organization, Training, Materiel, Leadership, Personnel and Facilities



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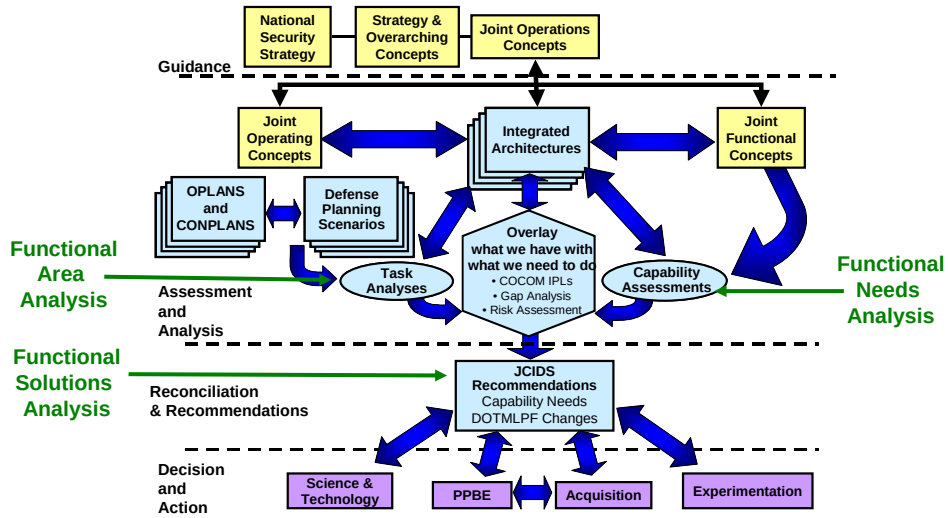
JCIDS Analysis



Adapted from CJCSI 3170.01C Joint Capabilities and Integration Development System, Figure A-1

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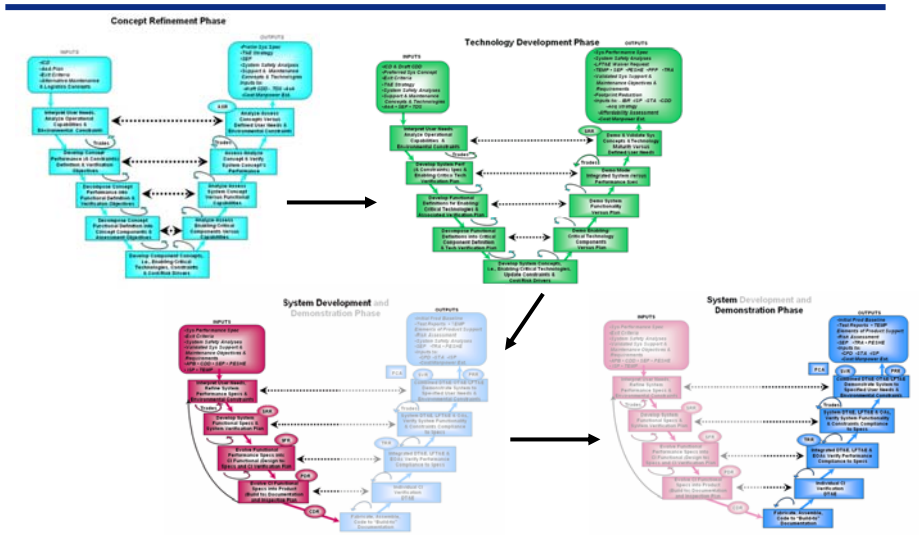
DAU Acquisition Guide 2006



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JCIDS Analysis

- Functional Area Analysis (FAA)
  - Identify operational tasks, conditions, and standards needed to accomplish military objectives
  - Result: Tasks to be reviewed in the FNA
- Functional Needs Analysis (FNA)
  - Assess ability of current and programmed capabilities to accomplish the tasks
  - Result: List of capability gaps
- Functional Solutions Analysis (FSA)
  - Operational based assessment of doctrine, organization, training, materiel, leadership/education, personnel, and facilities (DOTMLPF) approaches to solving capability gaps
  - Result: Potential integrated DOTMLPF approaches to capability gaps
- Post Independent Analysis
  - Independent analysis of approaches to determine best fit
  - Result: Initial Capabilities Document